METAL ACCUMULATIONS IN FISHES FROM MUSKOKA-HALIBURTON LAKES IN ONTARIO (1978 - 1984)

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METAL ACCUMULATIONS IN FISHES FROM MUSKOKA-HALIBURTON LAKES IN ONTARIO (1978-1984)

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ABSTRACT

Sixteen Muskoka-Haliburton lakes of varying buffering capacities were studied to assess the interrelationships between water quality and metal accumulations in fish.

Lakewater pH was inversely correlated with whole body concentrations of mercury in yearling yellow perch ($r = -0.80$; $p<0.01$). This relationship did not hold for lead and cadmium residues. Stepwise regression analyses indicated that dissolved organic carbon also explained some of the variability in mercury residues in perch. Mercury residues in perch were correlated ($r = 0.87$; $p<0.01$) with watershed area/lake volume ratios in headwater lakes, suggesting that mercury was released from the watersheds. Similar relationships were not observed for lead and cadmium.

Mercury residue trends were not evident in yearling yellow perch from the Muskoka-Haliburton study lakes during the study period 1978-1984.

Stepwise regression analyses selected lakewater pH, phytoplankton biovolume and mercury accumulations as significant factors influencing yearling yellow perch condition. Lakewater pH accounted for 58%, phytoplankton biovolume for 18% and mercury residues for 10% of the variability in perch condition.

Mercury concentrations in the edible portion (dorsal muscle) of a 30 cm "standard" bass were correlated ($r = -0.91$; $p<0.01$) with lakewater pH, and the mean mercury concentrations in bass from 7 of the 10 lakes sampled exceeded the Health and Welfare Canada Guideline (500 ng g^{-1}) for unrestricted fish consumption.

Mercury residues in whole yearling yellow perch samples were correlated ($r = 0.83$; $p<0.05$) with mercury concentrations in adult bass muscle tissue.

INTRODUCTION

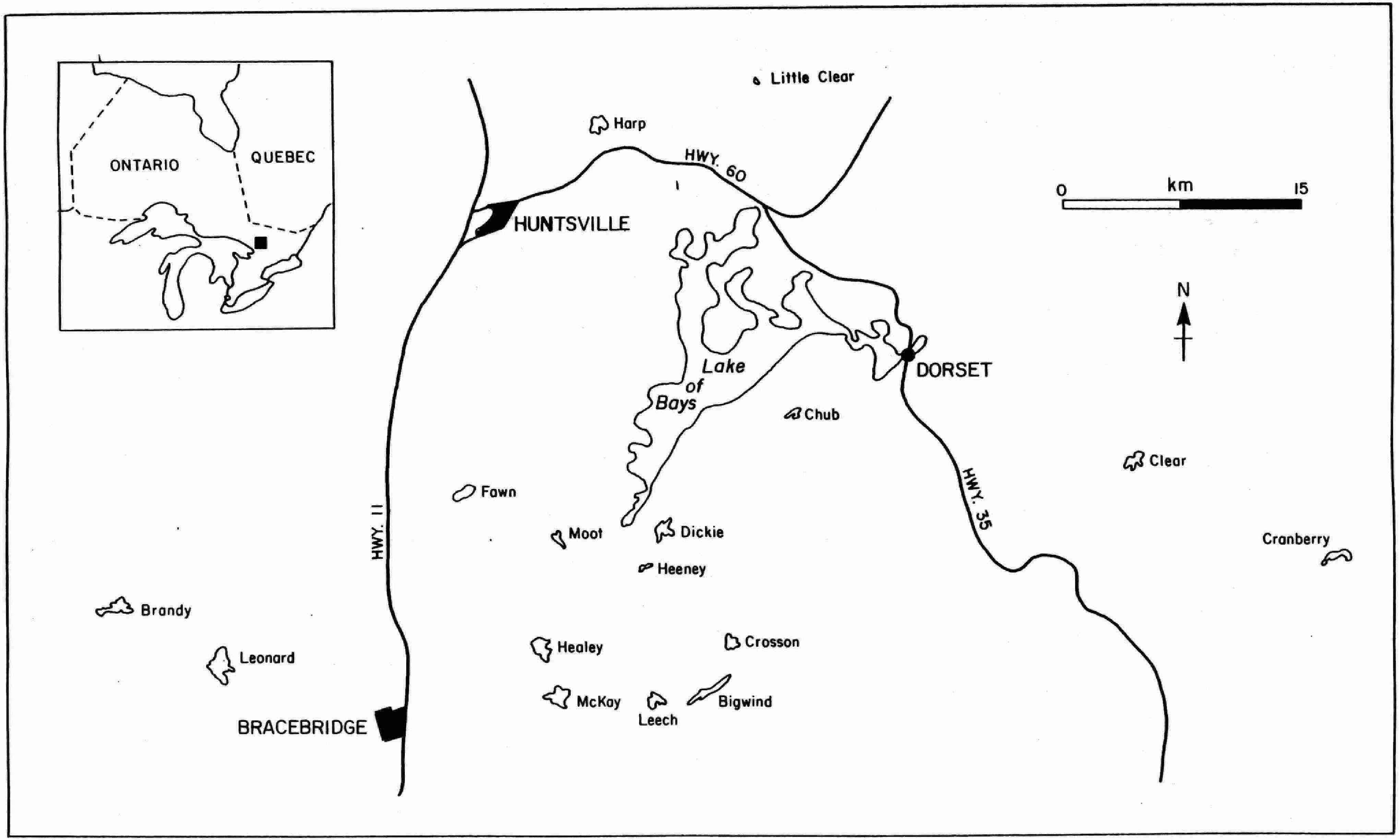
Increased metal concentrations in surface waters have been linked to acidic precipitation in areas where the acid-neutralizing capacities of soils and waters are low (Haines 1981). Under acidic conditions, metal solubility increases and metals are mobilized from watersheds and sediments (Beamish 1976; Scheider et al.1979; Dickson 1980; Schindler et al.1980; Bloomfield et al.1980), and there is evidence that fish from waters of low pH and alkalinities generally have higher metal residues (Scheider et al.1979; Thompson et al.1980; Glass and Loucks 1980; Wren and McCrimmon 1983).

While the combined effects of acidity and metal stress are often implicated in toxic responses (Jensen and Snekvik 1972; Baker and Schofield 1980), the role of metal body-burdens in fish toxicity and their chronic effects are poorly understood, particularly when complex mixtures of metals are involved (Spry et al.1981). This report presents observed associations between water quality and metal (Hg, Pb, Cd) accumulations in fish from the Muskoka-Haliburton lakes in Ontario and changes in fish condition related to acidity. Implications for human health are discussed.

STUDY AREA

Sixteen study lakes were selected to span a wide range of pH and alkalinity in the Muskoka-Haliburton region of south-central Ontario. Most of the lakes were situated on the Precambrian Shield, within a 50 km radius of Dorset, Ontario. The geology of the area and its effect on lake water chemistry has been previously documented (Dillon et al. 1978). The silicate bedrock is highly resistant to chemical weathering, with overburden consisting almost exclusively of shallow till. Lakes in this area are consequently dilute and weakly buffered. The exception was Cranberry Lake, a hardwater lake, with limestone outcroppings in its drainage basin. Lake locations are shown in Figure 1 and Table A1. Water chemistry and phytoplankton data are shown in Table A2.

Fig. 1: Location of the Muskoka-Haliburton study lakes.



METHODS

Fish Collections and Analyses

Yearling yellow perch (Perca flavescens) were seined or trapnetted from the study lakes from mid-July to mid-August between 1978 and 1984. Individual fish were measured (total length in mm) and weighed (to the nearest tenth of a gram) in all sampling years. Scale samples were collected from representative size groups in 1978, 1979, 1980 and 1981 to verify fish ages. Standard length (the distance between the tip of the snout to the last vertebra) was measured for some lakes in 1983 and for all lakes in 1984. Composite samples of 5 whole fish were placed in plastic bags, frozen by dry ice and stored at -20°C, prior to contaminant analysis. Analyses were done on whole fish composite samples after homogenization.

Adult bass were collected from the following Muskoka-Haliburton lakes: Basshaunt, Bay, Buck, Cranberry, Duck, Fawn, Heeney, Leonard and Walker Lakes in 1980 and from Dickie Lake in 1979 and 1980 (subsequently combined). Smallmouth bass (Micropterus dolomieui) were trapnetted in all lakes, except Cranberry and Fawn, where largemouth bass (Micropterus salmoides) were taken. Individual fish were measured (total length), weighed and scale samples collected for aging. Mercury determinations were done on boneless, skinless, dorsal muscle tissues for each individual fish.
Metal residue quantifications were done at the Ontario Ministry of the Environment Laboratories in Rexdale. Total mercury residues were determined using cold vapour flameless atomic absorption. Flameless atomic absorption spectroscopy with a P.E. 500 graphite furnace was used for total lead analyses. Cadmium concentrations were determined by atomic absorption. Detailed methodologies are available in the Outlines of Analytical Methods, Laboratory Services Branch, Ontario Ministry of the Environment (1981). All contaminant values reported were based on wet weight determinations.

Lake mean data were used for statistical analyses, where lake means were derived from pooling data for all the years sampled.

Fish Age Determination

Yellow perch scale samples from the 1978 and 1979 collections were aged by personnel of the Ontario Ministry of Natural Resources, Huntsville region. Scales from the 1980 and 1981 collections were aged by MacLaren Plansearch. All samples aged were found to be from yearling (1+) perch. Adult bass collections were aged by Dr. J. Casselman of the Fisheries Research Section, Ontario Ministry of Natural Resources, Maple, Ontario.

RESULTS AND DISCUSSION

Mercury Residues in Yearling Yellow Perch

Mercury residues in yearling yellow perch ranged from 31-183 ng g^{-1}, with Chub Lake having the highest and Clear Lake the lowest mercury concentrations (Table 1). We conclude that the anomalously low mercury residues in Clear Lake perch were influenced by the small drainage area. The terrestrial drainage area of Clear Lake is only a fraction (38%) of the lake surface area whereas the terrestrial drainage for the other study lakes constitutes the dominant portion of the whole catchment area. Watershed inputs of mercury have been documented to be important sources of mercury to lakes (Bloomfield et al. 1980; Meger 1985), and there is evidence of drainage area influence on mercury availability in this study. Mercury residues in yearling perch from eight headwater lakes were found to correlate ($r = 0.87$; $p<0.01$) with the drainage area/lake volume ratios (Figure 2). Headwater lakes in this study were defined as lakes without inflows from other lakes or major streams. For these reasons Clear Lake data have been excluded from further analyses.

Mercury residues in yearling yellow perch were inversely correlated ($r=-0.80$); $p<0.01$) with lakewater pH (Figure 3). Stepwise regression analyses indicated that lakewater pH and dissolved organic carbon may have had significant roles in mercury accumulation in perch. Lakewater pH accounted for 63% and dissolved organic carbon an additional 8% of the mercury residue variability in perch (Table 2). Other water quality parameters such as alkalinity, sulphate and calcium concentrations were not selected in the multiple regression.

The role of pH in mercury mobilization and transformation for biological uptake has been well documented. Reduced pH in surface waters leads to the production of monomethylmercury, a stable, bioaccumulative material (Fagerstrom and Jernelov, 1982; Wood 1980). Methylation of inorganic mercury is pH-dependent with a maximum production around pH 6 (Tomlinson et al. 1980; Wood 1980). Furthermore, methylmercury can be remobilized from sediments into the water column under reduced pH conditions (Miller and Akagi 1979; Jackson et. al. 1980).

TABLE 1: **Summary of lake mean metals residues in yearling yellow perch from the Muskoka-Haliburton study lakes.**
Values are means ±SD

Lake	pH	Metals (ng g^{-1})		
		Hg	Pb	Cd
Bigwind	6.50	109 ± 28	88 ± 91	45 ± 14
Brandy	6.61	134 ± 24	112 ± 51	52 ± 6
Chub	5.81	183 ± 12	363*	120*
Clear	5.81	31 ± 17	186 ± 107	104 ± 44
Cranberry	7.34	53 ± 32	78 ± 84	54 ± 31
Crosson	5.75	179 ± 20	310 ± 117	140 ± 21
Dickie	5.82	143 ± 29	242 ± 97	88 ± 17
Fawn	5.66	160 ± 17	270 ± 18	108 ± 22
Harp	6.56	118 ± 44	290 ± 152	184 ± 28
Healey	5.90	140 ± 44	149 ± 185	53 ± 18
Heeney	5.69	146 ± 27	354 ± 135	232 ± 51
Leech*	5.96	117*	119*	71*
Leonard	5.78	111 ± 42	247 ± 21	209 ± 83
Little Clear	6.69	76 ± 22	176 ± 127	136 ± 8
McKay	6.24	125 ± 40	81 ± 69	103 ± 8
Moot	5.63	139 ± 15	387 ± 118	36 ± 12

*sampled once

Fig. 2: Relationship between drainage basin area / lake volume and mercury residues in yearling yellow perch, using lake mean data for Muskoka-Haliburton headwater lakes.

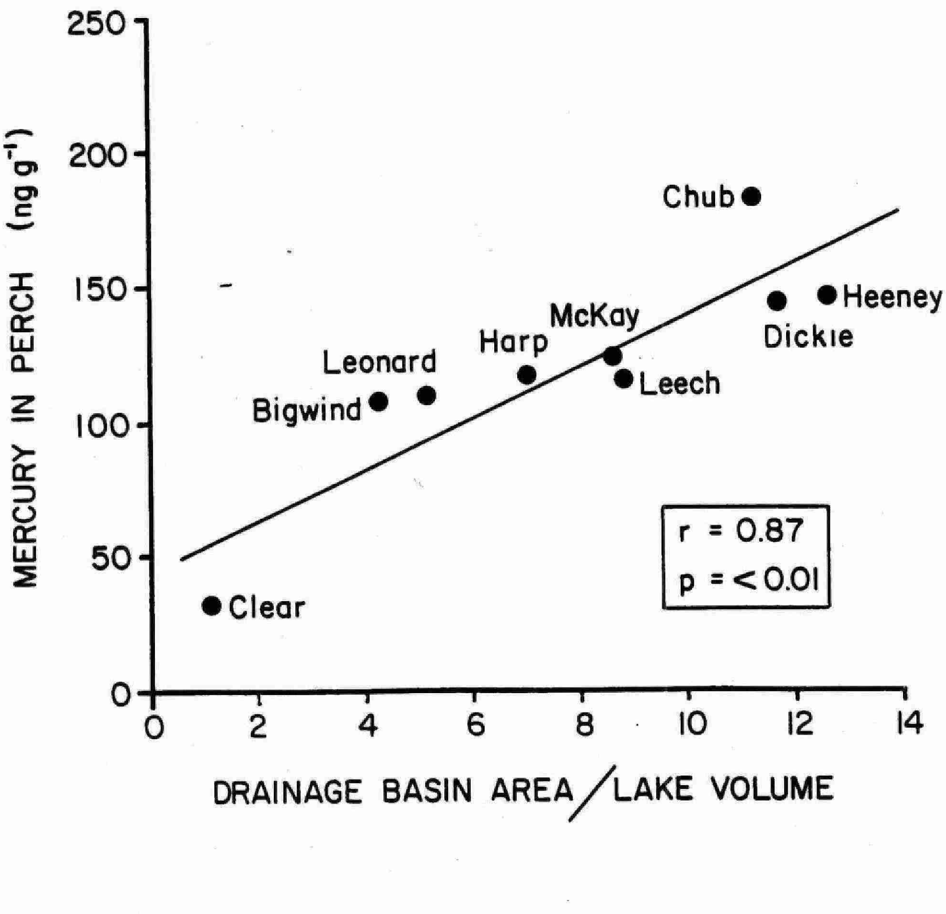


Fig. 3: Relationship between lake pH and mercury residues in yearling yellow perch in the Muskoka-Haliburton study lakes. Open circle (○) is Clear Lake.

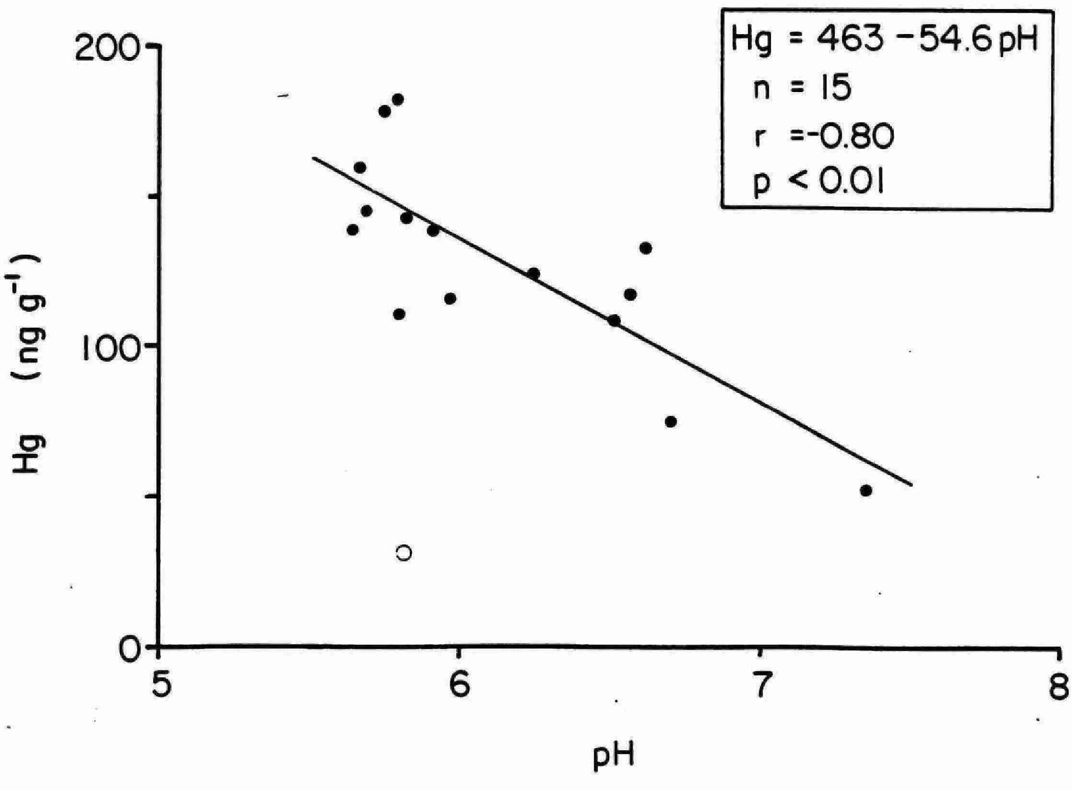


TABLE 2: Stepwise regression models for the prediction of metal residues in yearling yellow perch in the Muskoka-Haliburton study lakes. Independent variables (see Table A2 for units) included lake pH, dissolved organic carbon (DOC), total inflection point alkalinity (TIP), calcium and sulphate. For the mercury model Clear Lake data were excluded.

Dependent Variables	Selected Independent Variables (in order)	Cumulative r^2	Regression Model	p	SE
Hg	pH	0.63			
	DOC	0.71	Hg=-52.4 pH + 4.26 DOC + 428	<0.001	20.2
Pb	pH	0.41	Pb = 1055 - 137 pH	<0.01	84.8
Cd	no variables selected				

Since dissolved organic carbon is a component of the organic complex collectively known as humic matter, there is support in the literature for the observed link between dissolved organic carbon in lakewater and mercury in perch. Gjessing and Rogne (1982) have shown that increased humus content in water enhances metallic mercury solubility, and waterborne metal residues in Swedish lakes were found to correlate with lake colour and total organic carbon in lakewater. Saar and Weber (1982) conclude that fulvic acids, the most hydrophilic of the humic substances, can alter the geochemical mobility of metal ions by releasing metal ions adsorbed on sediments.

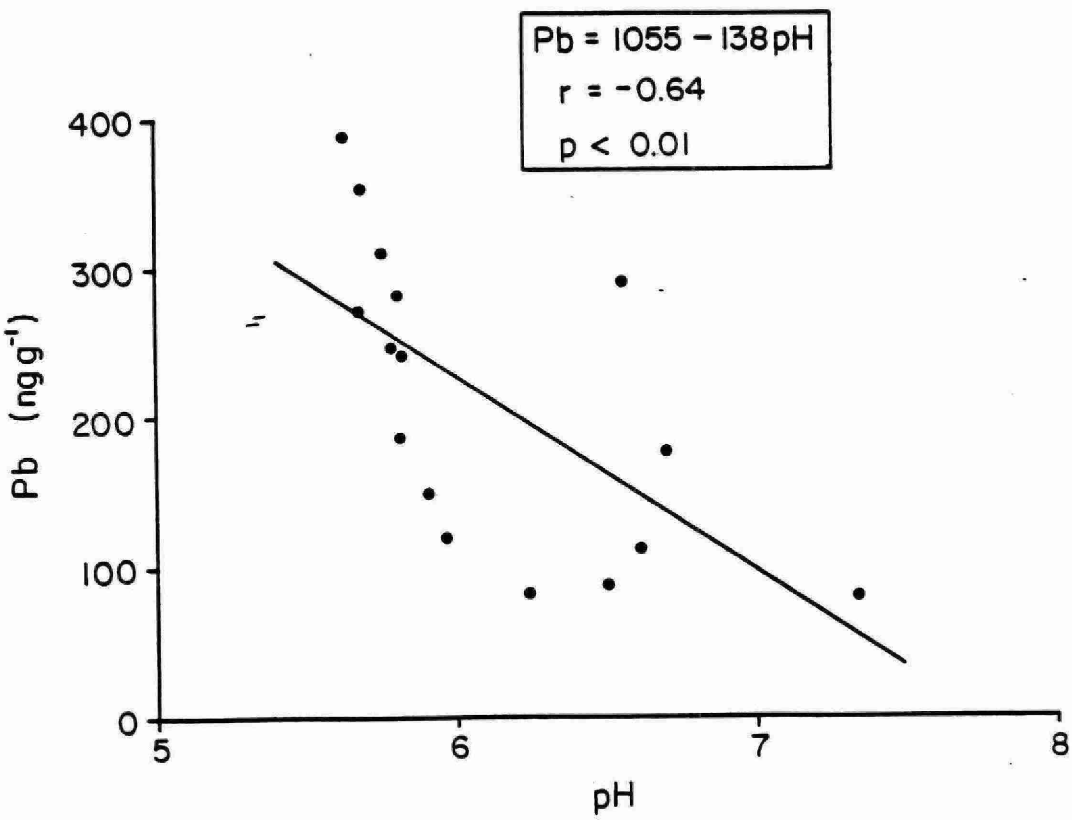
Although there are no known major geological deposits of mercury in the study area, mercury mobilization from geological origins cannot be ruled out. The acidification process can cause leaching of metals from the soils, rocks and lake sediments (Glass et al.1982; Schindler et al. 1980 ; Bloomfield et al.1980). Atmospheric inputs of mercury in the study area are documented. Deposition studies in 1979 at Dorset have shown that the total mercury flux to land and water surfaces ranged from 70-140 ug $m^{-2}yr^{-1}$, consisting mainly of elemental mercury (Barton et al.1981). Further studies in 1983 have shown that wet deposition at Dorset contained mercury concentrations ranging from 0.01-0.04 ug L^{-1} (Chan and Orr 1985). Atmospheric deposition studies in Scandinavia also conclude that airborne mercury deposition is an important factor in surface-water contamination (Brossett 1981; Bjorklund et al.1981).

While the origins and their relative contributions of mercury to the study lakes remain unknown, the observed associations between lakewater acidity and mercury accumulations in yearling yellow perch suggest that acidity plays a role in mercury mobilization and its transformation for biological availability.

Lead and Cadmium Residues in Yearling Yellow Perch

Lead residues in yearling yellow perch ranged between 78-387 ng g^{-1} (Table 1), and were inversely correlated ($r = -0.64$; $p<0.01$) with lakewater pH. However, the relationship was considered doubtful due to irregular lead residue distribution (Figure 4). Cadmium residues in perch were not correlated ($p>0.05$) with any of the water quality

Fig. 4: Relationship between lake pH and lead residues in yearling yellow perch from the Muskoka-Haliburton study lakes.



parameters tested. While lead and cadmium in yearling yellow perch did not correlate significantly with water quality parameters, the higher lead and cadmium concentrations in perch were generally found in the more acidic lakes (Table 1).

Beamish (1976), Dickson (1980) and Bjorklund et al.(1981) have shown that metal concentrations in water are related to lake acidities, yet the results from this study suggest that factors other than the water quality parameters considered may have influenced lead and cadmium bioavialability. Wiener and Giesy (1979) conclude that there is a need for metal speciation in order to understand their fate and bioavailability in organic softwater systems.

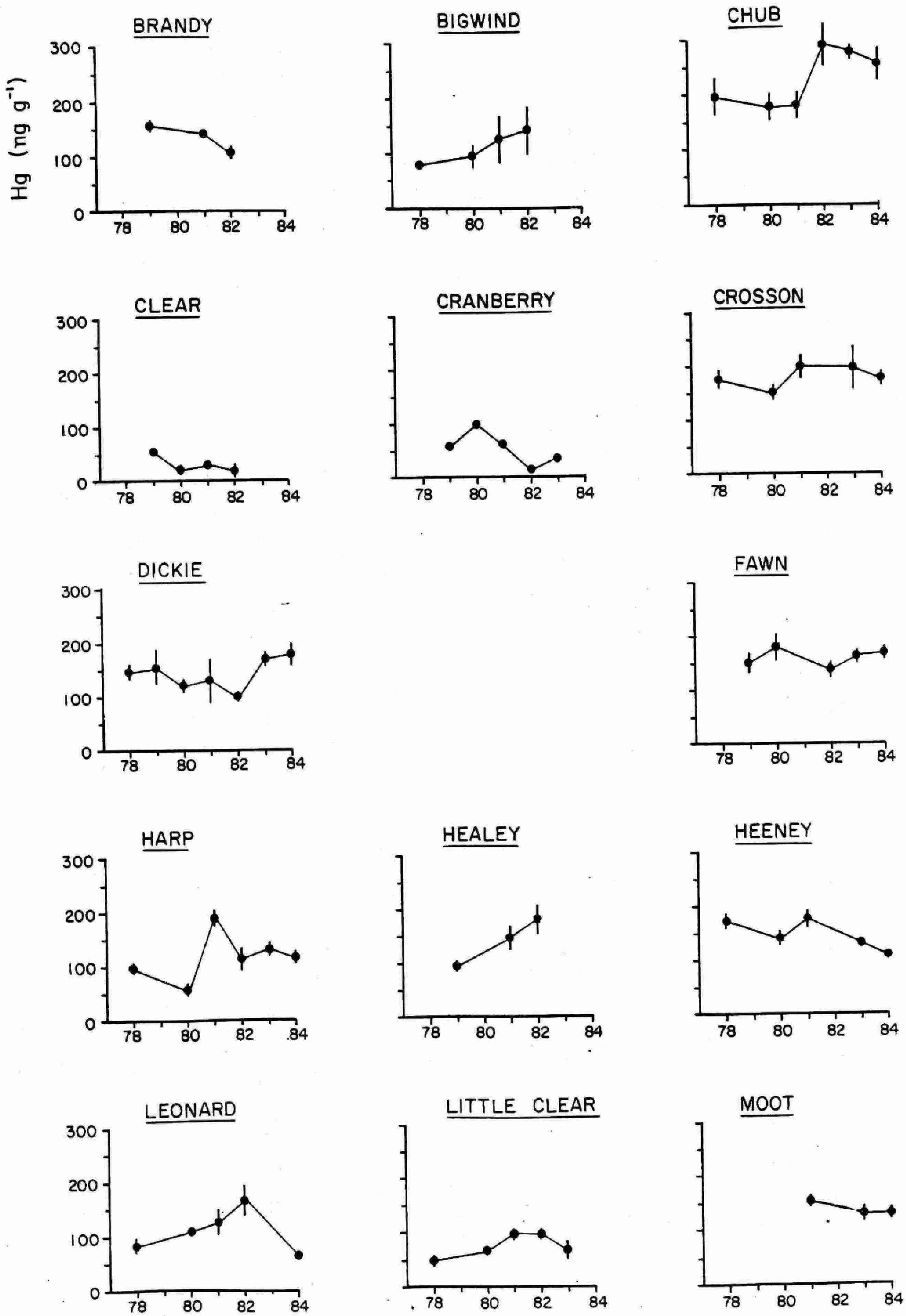
Lead and cadmium residues in yearling yellow perch from the more acidic study lakes were high when compared to published fish residue data from Ontario. Mean lead residues for the study lakes ranged from 78-387 ng g^{-1}, whereas reported lead concentrations for adult yellow perch from Lake Erie and Lake Ontario were in the 140-400 ng g^{-1} range, with the highest concentrations in Toronto harbour (Hodson et al,1984). Mean cadmium residues in yearling yellow perch from the study lakes ranged from 36-232 ng g^{-1}, while the National Research Council of Canada (1979) has reported cadmium concentrations of 10-100 ng g^{-1} for several fish species.

Temporal Trends in Metal Accumulations

Although mercury residues in yearling yellow perch fluctuated considerably on a year-to-year basis, no significant trends over the six year period were detected (Figure 5). Reasons for these mercury residue fluctuations are not known. There is no evidence in this data base that mercury levels were influenced by fish size.

Lead and cadmium data were limited to two annual collections in some lakes, therefore, trend evaluations were not attempted for these metals.

Fig.5: Mercury residue trends in yearling yellow perch in the Muskoka-Haliburton study lakes (means ± 95% confidence limits)



The apparent mercury residue increase in 1981 in perch from Chub Lake occurred at a time of site disturbances, and cannot therefore be considered a true trend. Rebuilding of a hydrological gauging weir on Inflow #2 involved excavation, draining and re-flooding of a holding reservoir. It has been shown that mercury residues in fish are often elevated from recently flooded reservoirs (Jones et al.1986). We conclude that the construction activities (September 1980 - August 1981) at Inflow #2 influenced mercury availability and input to Chub Lake. Mercury residue data for Chub Lake perch from 1981-1984 have therefore been excluded from calculations elsewhere in this report.

Condition Factor - Fish Health

Fish condition factor, or coefficient of condition was used as a measure of relative health in this study. It was estimated as follows: condition factor = fish weight (g) x 1000/standard length $(cm)^3$. When standard length was not measured, it was estimated from measured total length by the regression equation: standard length = 0.893 total length - 2.96 ($n = 392$, $r = 0.99$, $p<0.01$).

Fish condition factor is an expression of the relationship between total food intake, conversion efficiency and the requirements for maintenance and growth. Although condition factor may be indicative of fish health or a favourable environmental habitat, many factors may interact to affect fish condition (food availability, population density, predator-prey relationships, etc.). However, sampling a definable age class at a specified time of the year can provide average fish condition factors that are useful for determining the success of a given population (Gerkin 1968).

Yearling yellow perch condition factors in the Muskoka-Haliburton study lakes (Table 3) were significantly correlated ($r = 0.76$; $p<0.01$) with lakewater pH (Figure 6). Stepwise regression analysis was used to determine what other variables might influence fish condition. Independent variables selected, and included in the analysis, are summarized in Table 4. Variables affecting condition factor included lake pH, accounting for 58% of the observed variability in fish

TABLE 3: Summary of mean fish lengths, weights and condition factors for yearling yellow perch from the Muskoka-Haliburton study lakes. Condition factors were calculated from individual year mean data. (N = number of years of data.)

Lake	N	Total Length (cm)	Standard Length (cm)	Weight (g)	Condition Factor
Bigwind	4	8.9	7.7	7.0	14.7
Brandy	3	8.5	7.3	6.8	16.9
Chub	3	7.3	6.2	3.6	14.4
Clear	4	7.8	6.7	4.5	15.0
Cranberry	5	10.0	8.7	10.4	15.7
Crosson	5	7.7	6.6	4.0	13.5
Dickie	7	7.6	6.6	4.4	14.2
Fawn	5	8.9	7.6	6.1	13.4
Harp	6	7.0	5.9	3.0	14.4
Healey	2	8.8	7.6	6.1	14.3
Heeney	5	8.4	7.3	5.3	13.7
Leech	1	10.9	9.4	12.0	14.2
Leonard	5	8.9	7.7	6.7	14.1
Little Clear	5	6.5	5.5	2.8	15.8
McKay	2	9.9	8.6	9.4	14.9
Moot	3	7.9	6.7	4.2	13.8

Fig. 6: Relationship between lake pH and fish condition factor for yearling yellow perch from the Muskoka-Haliburton study lakes.

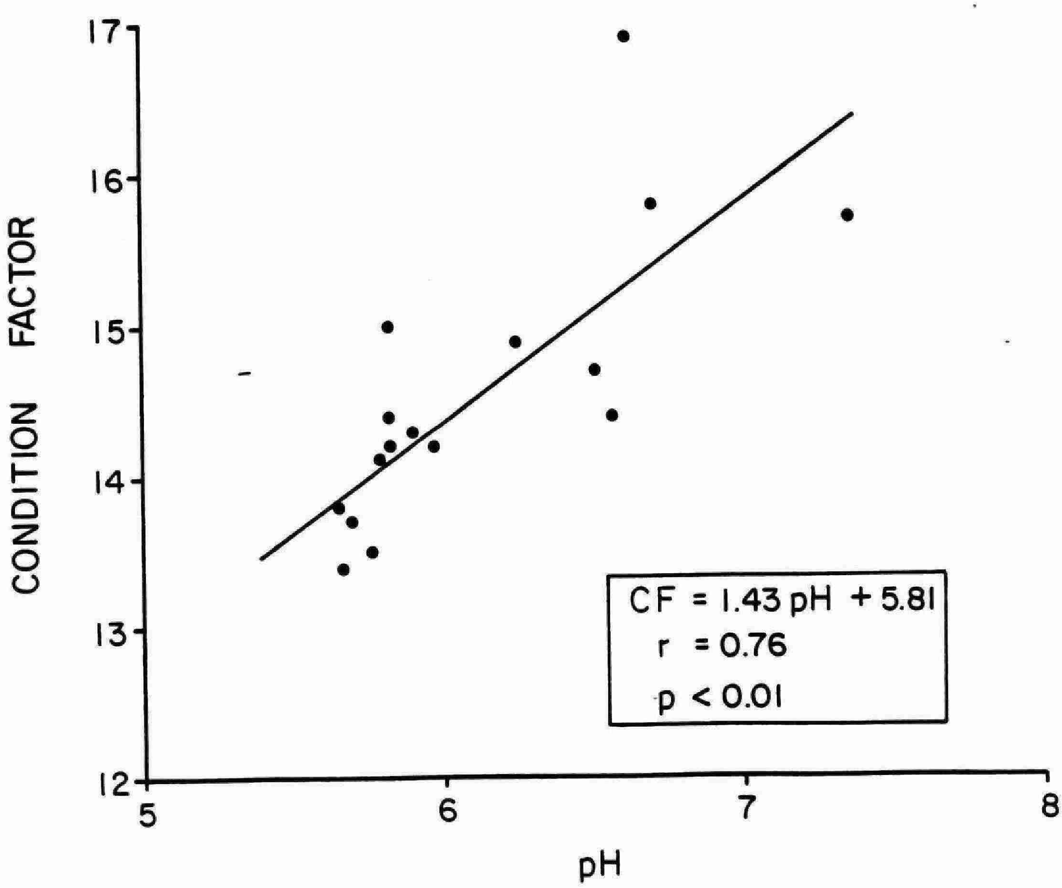


TABLE 4: Stepwise regression models for the prediction of yearling yellow perch conditions factors in the Muskoka-Haliburton study lakes. Independent variables included lake pH, dissolved organic carbon, total inflection point alkalinity, calcium, sulphate, metal residues in perch (mercury, lead and cadmium)and phytoplankton biovolume. For variable units see Tables 2 and 3.

Dependent Variable	Selected Independent Variables (in order of selection)	Cumulative r^2
Fish Condition	lake pH	0.58
	phytoplankton biovolume	0.76
	mercury residues	0.86

Condition = 0.938 pH + 0.573 phyto - 0.009 Hg + 9.40 ($p<0.001$, SE = 0.39)

condition, phytoplankton biovolume and mercury residues in perch, increasing explained variations in fish condition to 76 and 86%, respectively.

Varying environmental stresses associated with high acidity have resulted in both increased and decreased growth rates in yellow perch. Ryan and Harvey (1980) found increased growth rates in younger perch (age 1 to 3) in the LaCloche Mountain lakes and attributed this to reductions in inter- and intra-specific competition, while reduced growth rates were observed in older (piscivorous) perch, resulting from increased maintenance requirements in an acid medium and increased competition for a declining food source. Harvey (1981) found that perch condition improved with increasing acidity in four LaCloche Mountain lakes with a pH range of 4.1 to 5.4, in response to reduced competition, and identified pH 5.3 as the threshold for changed condition in yellow perch.

Since population data for zooplankton and benthic invertebrates were not available for the study lakes, phytoplankton biovolume was included in the regression analyses as an indicator of general lake productivities. Stepwise regression analyses indicated that yearling yellow perch condition was affected by phytoplankton biovolume in the study. However, there is no evidence that phytoplankton biomass is reduced in acidified lakes (Yan and Stokes 1978; Dillon et al.1979; Schindler 1980). There are indications, however, that the biomass of aquatic insects and amphipods have been reduced at pH levels of 6.0-5.7 (Leivestad and Muniz 1976; Sutcliffe and Carrick 1973).

Since immature insects and amphipods are the dominant food items of the older young-of-the-year and yearling perch (Whiteside et al.1985; Rodgers and Quadri 1982), the observed perch condition deterioration may reflect a scarcity of these food items in the more acidic lakes.

Bio-chemical assays using yearling yellow perch from the Muskoka-Haliburton study lakes have shown that perch from the more acidic lakes with higher metal concentrations have reduced protein synthesis (D. Nicholls - personal communication). It may be therefore inferred that the metal accumulations in perch were indicative of metal stress influencing fish condition. Kearns and Atchison (1979) found that increased cadmium residues in yellow perch were correlated with decreased fish growth. Increasing lead residues in juvenile brook trout (Salvelinus fontinalis) were found to cause reduced growth (Holcombe et al. 1976).

Whether the perch condition declines in the study lakes were primarily associated with the direct physiological stresses of acidity and metals, or the indirect effects associated with food availability and changes in fish community structures remains unclear. However, the reduced yearling yellow perch condition in the more acidic Muskoka-Haliburton lakes may be indicative of deteriorating water quality effects on fish.

Mercury Accumulations in Adult Bass - Human Health Implications

Mean mercury residues in adult bass muscle tissue (Table 5) ranged between 187-1121 ng g^{-1} wet weight, with a maximum individual fish concentration of 2600 ng g^{-1} for an 8 year old, 47 cm bass collected in Fawn Lake. In 7 of the 10 lakes where bass were collected, mean mercury levels exceeded the Health and Welfare Canada Guideline for unlimited fish consumption (500 ng g^{-1}, Ontario Ministry of the Environment 1985), while individual fish exceeded the guideline in 9 of the 10 lakes. Numbers of fish collected, mean lengths, weights and ages are also summarized in Table 5.

Positive correlations between fish lengths, weights and age versus mercury residues have been shown in several fish species (Scott and Armstrong 1972; Scott 1974, Abernathy and Cumbie 1977). Using both untransformed data and natural-log transformed variables, length was a better predictor of mercury residues in adult bass than either weight or age in the Muskoka-Haliburton study lakes.

TABLE 5: **Mercury residues in yearling yellow perch (means of whole fish composite samples collected from 1978 to 1980) and adult bass (skinless, boneless dorsal muscle tissue collected in 1980) from some Muskoka-Haliburton lakes, including lake pH, mean fish lengths, weights and ages for bass. All values are means ± standard deviation.**

	Lake pH	Yearling Perch		Adult Bass					
		N	Hg (ng g^{-1})	N	Age	Length (cm)	Weight (g)	Mean Hg (ng g^{-1})	Standard (30cm) Fish Hg (ng g^{-1})
Fawn	5.59	17	162 ± 30	14	4 ± 1	34 ± 6	650 ± 345	1121 ± 509	858
Heeney	5.73	17	159 ± 25	15	6 ± 2	34 ± 7	601 ± 359	874 ± 230	793
Leonard	5.78	17	94 ± 23	12	5 ± 1	35 ± 4	573 ± 222	689 ± 143	NE
Dickie	5.79	24	146 ± 32	36	NA	31 ± 4	426 ± 206	703 ± 344	568
Bay	6.3	7	93 ± 24	21	NA	30 ± 6	592 ± 358	614 ± 194	NE
Buck	6.8	NA	NA	14	5 ± 1	25 ± 4	216 ± 123	340 ± 140	505
Walker	6.8	5	110 ± 12	14	6 ± 1	27 ± 4	278 ± 200	569 ± 151	616
Basshaunt	7.0	NA	NA	11	6 ± 4	31 ± 8	547 ± 506	505 ± 244	474
Cranberry	7.34	141	79 ± 21	14	4 ± 1	30 ± 5	389 ± 211	187 ± 63	NE
Duck	7.90	16	39 ± 10	15	7 ± 2	33 ± 6	458 ± 280	209 ± 161	134

NA - not available

NE - no estimate (see text)

The relationship between fish length and mercury residue was expressed by the geometric curve equation:

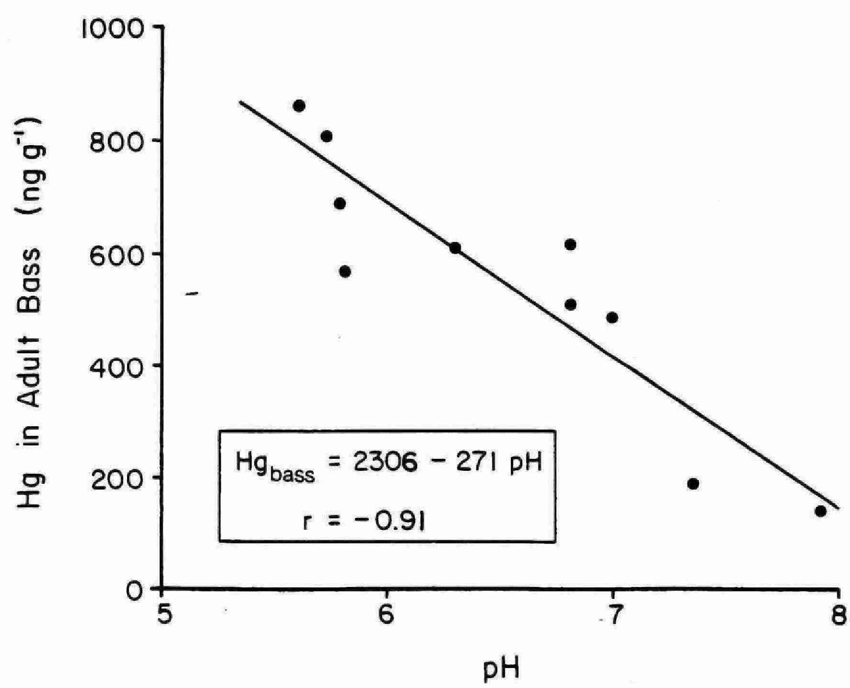
$$Hg = a\ \text{length}^b \text{ or } \log Hg = \log a + b \log \text{length}$$

This regression equation is used to develop the Ontario Ministry of the Environment fish consumption guidelines (M.O.E. 1985). Mercury accumulations in adult bass muscle from the Muskoka-Haliburton lakes were significantly ($p<0.05$) correlated with total fish length in 7 of the 10 study lakes.

To facilitate comparisons of mercury residue data for bass from different lakes and to reduce the bias introduced by varying sizes and ages, a standard size (30 cm) was employed. A length of 30 cm was representative of bass in all the sampled lakes and it was a reasonable size that fishermen would keep for consumption. Regression equations for mercury versus length (Table A5) were used to estimate mercury levels for the standard size bass in each lake. In the lakes where significant correlations between mercury residues and lengths were not evident (Bay, Cranberry, Leonard), the mean mercury content of all fish sampled was chosen as the most representative estimate available. Mean fish lengths in Bay, Cranberry and Leonard lakes approximated the selected 30 cm "standard" fish length. Mean mercury contents for Bay, Cranberry and Leonard lakes were used in Figure 7.
Fish length - mercury content regression equations were used to calculate the unrestricted consumption guideline (500 ng g^{-1}) limits for the lakes studied. These limits are summarized in Table A5, and they indicate critical lengths of adult bass beyond which mercury residues may exceed the guideline.

Mercury residues in the "standard" 30 cm bass were significantly correlated with lake pH ($r = -0.91$; $p<0.01$; Figure 7). This relationship suggests that bass lakes with pH <6.7 are more likely to contain individual bass with mercury residues in excess of the unrestricted Consumption Guidelines of 500 ng g^{-1}. Considering that the prevailing pH regimes in a substantial number of Muskoka-Haliburton lakes are less than 6.7 (Apios 1982), several other lakes in this region may have bass with elevated mercury levels. It may therefore be necessary to expand the Ontario Sportfish Testing Program in the Muskoka-Haliburton area.

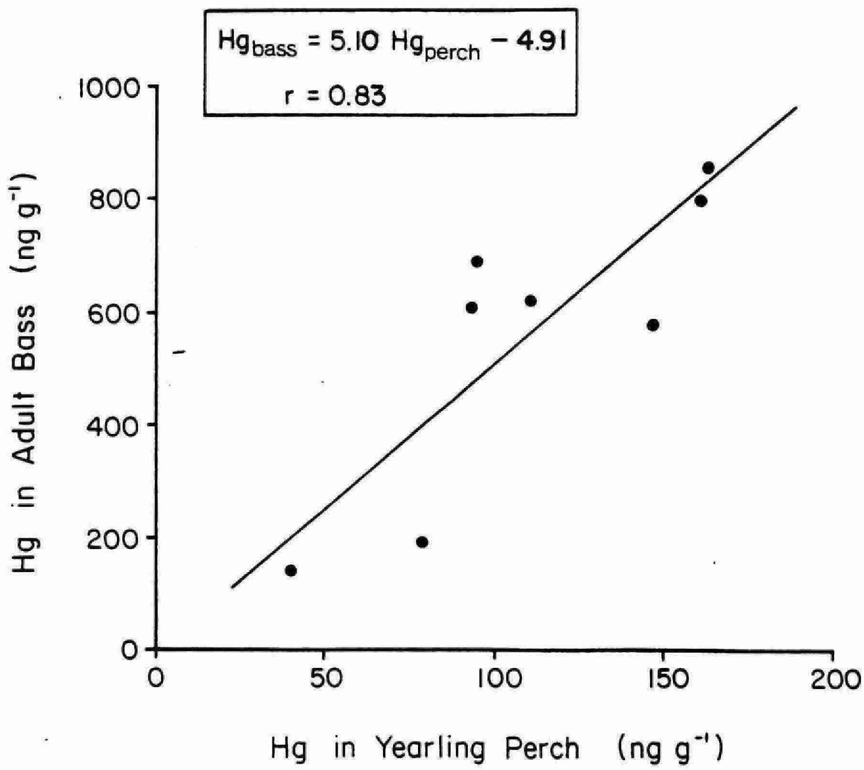
Fig. 7: Relationship between lake pH and mercury residues in standard 30 cm bass in the Muskoka-Haliburton study lakes.



Yearling Yellow Perch - Adult Bass Mercury Residue Relationships

Mercury residues in whole yearling yellow perch samples were found to be positively correlated ($r = 0.83$; $p<0.01$) with mercury concentrations in bass muscle tissue (Figure 8). This relationship may serve as a basis for predicting bass mercury residue levels in lakes where intense bass harvesting may be detrimental to the fishery. While there appears to be a strong correlation between mercury levels in yearling yellow perch and adult bass in the study lakes, further work is needed to test the reliability of these findings before perch samples are used as surrogates in predicting mercury availability.

Fig. 8: Relationship between mercury residues in yearling yellow perch and standard 30cm bass in the Muskoka-Haliburton study lakes.



CONCLUSIONS

The findings of this study indicate that elevated mercury accumulations in yearling yellow perch were related to increased lakewater acidity, increased dissolved organic carbon concentrations and high watershed size/lake volume ratios. While there are no known deposits of mercury bearing ores in the study area, geological sources as well as mercury inputs from the atmosphere may contribute to fish contamination.

During the six year period sampled (1978-1984), trends for mercury residues in yearling yellow perch were not evident in the study lakes.

Fish condition as an indicator of environmental stress is non-specific and reflects complex biological and physico-chemical interactions. While fish condition cannot be related to fish health in a specific way, the observed associations between depressed lake pH, elevated mercury accumulations and reduced yearling yellow perch condition suggests impaired environmental quality.

Mean mercury residues in adult bass muscle tissue exceeded the Health and Welfare Canada Guideline in seven of the ten lakes sampled, causing concern for the quality of the bass fishery. Considering that the pH regimes in a substantial number of Muskoka-Haliburton lakes are depressed, several other lakes may have bass populations with elevated mercury levels. It is therefore recommended that the Ontario Sportfish Testing Program be expanded to assess the extent of mercury contamination in the region.

The relationship between mercury concentrations in yearling yellow perch and adult bass offers opportunities to use the perch samples as a means of predicting mercury levels in the more valued sportfish. To test the reliability of these preliminary findings, there is a need to expand the data base.

ACKNOWLEDGEMENTS

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APPENDICES

TABLE A1

Location of the Muskoka-Haliburton Study Lakes

Lake	Latitude	Longitude	Township
Bigwind	45 03	79 03	Oakley
Brandy	45 07	79 32	Watt
Chub	45 13	78 59	Ridout
Clear	45 11	78 43	Sherborne
Cranberry	45 08	78 33	Guilford
Crosson	45 05	79 02	Oakley
Dickie	45 09	79 05	McLean
Fawn	45 10	79 15	Macaulay
Harp	45 23	79 08	Chaffey
Healey	45 05	79 11	Macauley
Heeney	45 08	79 06	McLean
Leech	45 03	79 06	Oakley
Leonard	45 05	79 27	Monck
Little Clear	45 24	79 01	Sinclair
McKay	45 03	79 10	Draper
Moot	45 09	79 10	Mclean

TABLE A2

Summary of chemical parameters and phytoplankton data for the Muskoka-Haliburton study lakes. Chemical data values are whole year means, calculated as the arithmetic mean of unstratified period and epilimnetic (stratified period) measurements. Phytoplankton data are the means of May to October collections sampled between 1978 and 1984.

Lake	pH	TIP alk.	Calcium	DOC	Sulphate	Phytoplankton
		(mg l^{-1})				(mm^3L^{-1})
Bigwind	6.50	2.7	2.9	3.4	7.8	0.405
Brandy	6.61	7.1	4.1	11.0	7.3	4.045
Chub	5.81	0.6	2.6	5.1	8.5	1.010
Clear	5.81	0.3	2.6	1.9	8.6	0.469
Cranberry	7.34	16.0	6.3	3.9	10.8	0.258
Crosson	5.75	0.5	2.2	4.2	7.5	0.615
Dickie	5.82	0.7	2.5	5.1	7.7	1.030
Fawn	5.66	0.9	2.6	8.9	7.5	0.774
Harp	6.56	3.3	3.0	4.2	8.4	0.946
Healey	5.90	1.5	2.8	6.8	7.1	0.947
Heeney	5.69	0.3	2.2	3.0	7.7	0.547
Leech	5.96	1.6	2.7	4.0	8.0	0.638
Leonard	5.78	0.4	2.7	3.8	7.6	0.381
Little Clear	6.69	4.8	3.1	2.7	7.6	0.566
McKay	6.24	1.7	3.0	5.3	7.5	0.345
Moot	5.63	0.8	1.9	6.0	5.6	1.515

TABLE A3: Summary of yearly mean metal residues in yearling yellow perch from the Muskoka-Haliburton study lakes. Values are the mean ± standard deviation.

Lake	Year	N	Total Length (mm)	Hg (ng g^{-1})	Pb (ng g^{-1})	Cd (ng g^{-1})
Bigwind	1978	6	7.4 ± 0.5	78 ± 9		
	1980	5	9.8 ± 0.3	94 ± 22		
	1981	6	8.4 ± 0.4	125 ± 43	152 ± 50	35 ± 14
	1982	4	10.0 ± 0.2	140 ± 42	24 ± 19	55 ± 20
Brandy	1979	8	8.1 ± 0.3	155 ± 13		
	1981	6	8.5 ± 0.3	140 ± 9	148 ± 31	47 ± 32
	1982	5	9.0 ± 0.4	108 ± 12	76 ± 41	56 ± 9
Chub	1978	7	8.2 ± 0.6	197 ± 38		
	1980	7	7.3 ± 0.1	173 ± 27		
	1981	7	6.4 ± 0.2	179 ± 24	363 ± 37	120 ± 23
	1982	7	9.7 ± 0.5	289 ± 46	126 ± 24	214 ± 97
	1983	7	8.0 ± 0.1	276 ± 14	415 ± 71	218 ± 57
	1984	5	9.7 ± 0.4	254 ± 30	218 ± 23	198 ± 75
Clear	1979	6	7.9 ± 0.2	55 ± 5		
	1980	7	7.9 ± 0.4	20 ± 9		
	1981	6	6.9 ± 0.2	30 ± 6	278 ± 79	73 ± 8
	1982	6	8.3 ± 0.6	20 ± 12	93 ± 24	135 ± 25
Cranberry	1979	7	10.6 ± 1.0	59 ± 4		
	1980	7	9.3 ± 0.4	99 ± 7		
	1981	7	10.0 ± 0.3	61 ± 9	60 ± 45	41 ± 7
	1982	7	9.7 ± 0.3	13 ± 7	<5	32 ± 13
	1983	6	10.5 ± 0.3	35 ± 6	168 ± 32	90 ± 44
Crosson	1978	10	6.7 ± 0.2	175 ± 20		
	1980	7	7.7 ± 0.2	150 ± 14		
	1981	7	7.2 ± 0.2	198 ± 23	294 ± 113	114 ± 32
	1983	7	8.4 ± 0.2	197 ± 42	435 ± 83	159 ± 44
	1984	7	8.4 ± 0.2	177 ± 14	202 ± 14	117 ± 29
Dickie	1978	10	6.7 ± 0.1	147 ± 16		
	1979	10	5.6 ± 0.1	155 ± 44		
	1980	4	9.2 ± 1.1	120 ± 14		
	1981	4	8.3 ± 1.0	130 ± 42		
	1982	7	7.6 ± 0.5	100 ± 6q	140 ± 76	73 ± 18
	1983	6	7.6 ± 0.3	171 ± 15	334 ± 90	86 ± 24
	1984	7	8.5 ± 0.4	181 ± 19	252 ± 43	106 ± 28

TABLE A3: (Cont'd)

Lake	Year	N	Total Length (mm)	Hg (ng g^{-1})	Pb (ng g^{-1})	Cd (ng g^{-1})
Fawn	1979	10	8.8 ± 0.4	151 ± 24		
	1980	7	9.5 ± 1.0	179 ± 32		
	1982	5	8.4 ± 0.2	136 ± 17		
	1983	6	9.1 ± 0.4	163 ± 12	282 ± 49	92 ± 19
	1984	6	8.5 ± 0.3	170 ± 13	257 ± 4	123 ± 31
Harp	1978	10	6.5 ± 0.2	96 ± 7		
	1980	7	7.2 ± 0.1	57 ± 13		
	1981	7	6.9 ± 0.2	190 ± 15		
	1982	7	6.7 ± 0.3	114 ± 22	157 ± 55	160 ± 67
	1983	7	6.9 ± 0.1	132 ± 13	456 ± 143	215 ± 64
	1984	7	7.5 ± 0.1	116 ± 13	259 ± 19	176 ± 33
Healey	1979	10	8.3 ± 0.2	93 ± 11		
	1981	7	9.3 ± 0.4	147 ± 34	280 ± 123	65 ± 8
	1982	5	-	180 ± 28	18 ± 10	40 ± 22
Heeney	1978	10	7.9 ± 0.1	171 ± 22		
	1980	7	9.4 ± 0.3	141 ± 19		
	1981	7	8.0 ± 0.1	176 ± 15	233 ± 27	219 ± 42
	1983	7	8.4 ± 0.2	133 ± 8	499 ± 94	288 ± 61
	1984	7	8.5 ± 0.2	110 ± 8	331 ± 31	189 ± 43
Leech	1981	7	10.9 ± 0.6	117 ± 10	119 ± 94	71 ± 15
Leonard	1978	10	7.5 ± 0.1	83 ± 14		
	1980	7	8.3 ± 0.2	109 ± 7		
	1981	7	8.8 ± 0.3	129 ± 26	230 ± 58	113 ± 20
	1982	7	10.8 ± 0.5	170 ± 35	240 ± 34	260 ± 54
	1984	7	9.2 ± 0.2	63 ± 5	270 ± 15	253 ± 56
Little Clear	1978	10	7.0 ± 0.1	47 ± 8		
	1980	7	6.9 ± 0.3	69 ± 9		
	1981	7	6.6 ± 0.4	99 ± 12		
	1982	5	6.6 ± 0.3	96 ± 11	86 ± 11	130 ± 14
	1983	5	5.3 ± 0.2	68 ± 16	265 ± 33	142 ± 44
McKay	1981	7	9.8 ± 0.2	153 ± 8	130 ± 63	108 ± 5
	1982	6	10.0 ± 0.6	97 ± 14	32 ± 4	97 ± 19
Moot	1981	7	7.4 ± 0.2	156 ± 10	520 ± 233	50 ± 14
	1983	7	8.0 ± 0.4	130 ± 14	349 ± 67	28 ± 4
	1984	7	8.3 ± 0.2	131 ± 11	293 ± 46	30 ± 6

TABLE A4: Summary of mean fish lengths, weights and condition factors for yearling yellow perch from the Muskoka-Haliburton study lakes. Condition factors were calculated from individual fish data. Standard lengths followed by an asterisk(*) are measured values, all others are estimated from the equation standard length = 0.893 total length -2.96; n = 392; r = 0.99, p<0.01. Values are the mean ± standard deviation.

Lake	Year	N	Total Length (mm)	Standard Length (mm)	Weight (g)	Condition Factor
Bigwind	1978	6	74 ± 5	63 ± 5	3.6 ± 0.9	14.0 ± 0.7
	1980	5	98 ± 3	85 ± 2	9.7 ± 0.7	15.9 ± 0.8
	1981	6	84 ± 4	72 ± 3	5.2 ± 0.8	13.9 ± 1.0
	1982	4	100 ± 2	86 ± 1	9.5 ± 0.4	14.9 ± 0.5
Brandy	1979	8	81 ± 3	70 ± 3	5.4 ± 0.6	16.0 ± 1.3
	1981	6	85 ± 3	73 ± 3	6.3 ± 0.7	16.0 ± 0.9
	1982	5	90 ± 4	77 ± 4	8.6 ± 0.7	18.8 ± 1.1
Chub	1978	7	82 ± 6	71 ± 5	5.5 ± 1.3	15.4 ± 1.4
	1980	7	73 ± 1	62 ± 1	3.2 ± 0.2	13.7 ± 0.3
	1981	7	64 ± 2	54 ± 2	2.2 ± 0.2	14.0 ± 0.9
	1982	7	97 ± 5	84 ± 5	8.1 ± 2.5	13.4 ± 1.5
	1983	7	80 ± 1	68 ± 1	4.3 ± 0.2	13.4 ± 0.3
	1984	5	97 ± 4	83 ± 3*	7.7 ± 0.6	13.5 ± 0.6
Clear	1979	6	79 ± 2	68 ± 2	4.4 ± 0.3	14.1 ± 0.6
	1980	7	79 ± 4	68 ± 3	4.4 ± 0.8	14.1 ± 0.7
	1981	6	69 ± 2	59 ± 2	3.2 ± 0.2	15.5 ± 0.7
	1982	6	83 ± 6	71 ± 5	5.9 ± 1.4	16.1 ± 0.9
Cranberry	1979	7	106 ± 10	92 ± 9	12.9 ± 3.6	16.2 ± 0.6
	1980	7	93 ± 4	80 ± 4	7.5 ± 1.0	14.8 ± 0.6
	1981	7	100 ± 3	87 ± 3	9.8 ± 0.9	15.0 ± 0.5
	1982	7	97 ± 3	84 ± 3	10.2 ± 0.7	17.1 ± 0.7
	1983	6	105 ± 3	91 ± 4*	11.5 ± 1.0	15.5 ± 0.9
Crosson	1978	10	67 ± 2	57 ± 2	2.5 ± 0.2	13.3 ± 0.7
	1980	7	77 ± 2	66 ± 2	4.3 ± 0.3	15.0 ± 0.7
	1981	7	72 ± 2	61 ± 2	2.9 ± 0.2	12.6 ± 0.3
	1983	7	84 ± 2	72 ± 2	5.1 ± 0.4	13.8 ± 0.6
	1984	7	84 ± 2	73 ± 2*	5.0 ± 0.4	13.0 ± 0.3
Dickie	1978	10	67 ± 1	57 ± 1	2.6 ± 0.2	14.0 ± 0.9
	1979	10	56 ± 1	47 ± 1	1.6 ± 0.1	15.1 ± 0.8
	1980	4	96 ± 11	83 ± 9	8.8 ± 3.0	15.1 ± 0.6
	1981	4	83 ± 10	71 ± 9	5.1 ± 1.9	13.7 ± 0.9
	1982	7	76 ± 5	64 ± 4	3.8 ± 0.9	14.0 ± 1.6
	1983	6	76 ± 3	65 ± 3*	3.9 ± 0.6	14.1 ± 0.5
	1984	7	85 ± 4	72 ± 3*	5.1 ± 0.7	13.5 ± 0.4

TABLE A4: (Cont'd)

Lake	Year	N	Total Length (mm)	Standard Length (mm)	Weight (g)	Condition Factor
Fawn	1979	10	88 ± 4	76 ± 4	6.3 ± 1.0	14.5 ± 0.6
	1980	7	95 ± 10	82 ± 9	8.3 ± 2.6	14.5 ± 0.4
	1982	5	84 ± 2	72 ± 2	4.5 ± 0.3	12.1 ± 0.3
	1983	6	91 ± 4	79 ± 3*	6.5 ± 0.8	13.2 ± 0.4
	1984	6	85 ± 3	73 ± 3*	5.0 ± 0.6	12.8 ± 0.7
Harp	1978	10	65 ± 2	55 ± 2	2.4 ± 0.1	14.6 ± 1.1
	1980	7	72 ± 1	61 ± 1	3.7 ± 0.1	16.3 ± 0.6
	1981	7	69 ± 2	58 ± 2	2.3 ± 0.1	11.3 ± 0.7
	1982	7	67 ± 3	57 ± 2	2.9 ± 0.2	15.4 ± 1.0
	1983	7	69 ± 1	59 ± 1	3.1 ± 0.2	15.4 ± 0.4
	1984	7	75 ± 1	64 ± 1*	3.5 ± 0.3	13.2 ± 0.6
Healey	1979	10	83 ± 2	71 ± 2	5.5 ± 0.5	15.7 ± 0.6
	1981	7	93 ± 4	80 ± 3	6.7 ± 0.9	12.8 ± 0.7
	1982	5	-	-	-	-
Heeney	1978	10	79 ± 1	68 ± 1	4.2 ± 0.2	13.8 ± 0.8
	1980	7	94 ± 3	81 ± 3	7.7 ± 0.8	14.4 ± 0.6
	1981	7	80 ± 1	68 ± 1	4.0 ± 0.2	12.4 ± 0.5
	1983	7	84 ± 2	72 ± 2	5.6 ± 0.3	15.2 ± 0.7
	1984	7	85 ± 2	74 ± 2*	5.1 ± 0.4	12.7 ± 0.4
Leech	1981	7	109 ± 6	94 ± 6	12.0 ± 2.3	14.2 ± 0.4
Leonard	1978	10	75 ± 1	64 ± 1	3.9 ± 0.4	14.8 ± 1.1
	1980	7	83 ± 2	71 ± 2	5.1 ± 0.4	14.0 ± 0.3
	1981	7	88 ± 3	76 ± 3	5.8 ± 0.6	13.5 ± 0.5
	1982	7	108 ± 5	94 ± 5	11.6 ± 0.3	14.1 ± 0.9
	1984	7	92 ± 2	79 ± 2*	6.9 ± 0.5	14.0 ± 0.4
Little Clear	1978	10	70 ± 1	60 ± 1	3.2 ± 0.2	15.0 ± 0.2
	1980	7	69 ± 3	59 ± 2	3.6 ± 0.3	17.0 ± 0.9
	1981	7	66 ± 4	56 ± 3	2.8 ± 0.5	15.4 ± 0.7
	1982	5	66 ± 3	56 ± 3	3.2 ± 0.4	18.4 ± 0.7
	1983	5	53 ± 2	45 ± 2*	1.2 ± 0.1	13.2 ± 0.7
McKay	1981	7	98 ± 2	84 ± 2	8.2 ± 0.7	13.7 ± 0.6
	1982	6	100 ± 6	87 ± 5	10.6 ± 1.3	16.1 ± 1.2
Moot	1981	7	74 ± 2	63 ± 2	3.5 ± 0.2	13.9 ± 0.9
	1983	7	80 ± 4	68 ± 3	4.6 ± 0.6	14.4 ± 0.4
	1984	7	83 ± 2	71 ± 2*	4.6 ± 0.4	13.0 ± 0.7

TABLE A5: Relationship between total length (cm) and mercury residues (ng g^{-1}) in adult bass from the Muskoka-Haliburton study lakes, estimated mercury content in 30 cm bass and estimated lengths of bass with mercury levels exceeding the human health guideline for unlimited consumption (>500 ng g^{-1}). Computations were performed on log transformed variables, and lakes are arranged from lower to highest pH.

Lake	N	Regression Equation	r	Estimated Hg in 30 cm bass (ng g^{-1})	Length of Bass with >500 ng g^{-1} mercury (cm)	pH
Fawn	14	log Hg = 1.69 log length + 0.440	0.78*	873	21	5.59
Heeney	15	log Hg = 0.696 log length + 1.87	0.60*	794	16	5.73
Leonard	12	log Hg = 0.363 log length + 2.27	0.24	NE	<29 (all bass exceeded guideline)	5.78
Dickie	36	log Hg = 2.82 log length + 1.40	0.82*	594	28	5.79
Bay	21	log Hg = 0.544 log length + 1.97	0.41	NE	NE	6.30
Buck	14	log Hg = 2.25 log length - 0.626	0.76*	506	30	6.80
Walker	14	log Hg = 0.983 log length + 1.34	0.61*	624	24	6.80
Basshaunt	11	log Hg = 1.45 log length + 1.60	0.91*	475	31	7.00
Cranberry	14	log Hg = 0.441 log length + 1.60	0.21	NE	>39 (all bass below guideline)	7.34
Duck	15	log Hg = 1.69 log length - 2.37	0.90*	139	46	7.90

* - $p < 0.01$
** - $p < 0.05$
NE - no estimate ($p>0.05$)